Final Report

PEARL: An Improved Tactile
Graphics Production System

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Purpose

The objective of this project was to improve the quality of paper tactile graphic displays produced in APH's sterograph department by developing a new system for embossing the metal masters. Previously, APH personnel embossed images in zinc and iron plates by hammering them into the metal with an assortment of stake and die sets. Only one linear symbol, a thin solid line of low elevation and poor tactile quality, could be made semiautomatically, by using a tooling device which resembled a sewing machine in its operation. All other lines had to be produced in a piecemeal fashion with the stake and die sets. As it was stated in the Guidelines for Mathematical Diagrams (1980): "There is a pressing need for engineering research to create new methods and tools which will increase the variety of lines and symbols that can be produced using metal plates" (p. iv).

In comparison to our previous method of slate embossing, the new system is superior in terms of the quantity (displays embossed per unit time) quality (tactual clarity), versatility (symbol variety), and consistency of its output. In general, the new device reduces the variability in symbol height which previously resulted from moment to moment fluctuations in hammering force. It permits the employment of different levels of relief for the point, line, and areal symbols, a design variable which Nolan and Morris (1971) identified as a potent one in improving the readability of graphic displays. Moreover, it reduces operator arm and hand fatigue caused by hammering, thereby

allowing the operator to make more efficient use of his/her work periods. It is also likely that the training of new personnel will be facilitated by the new system by eliminating the learning of the rather complex perceptual-motor skills necessitated by the previous method of plate embossing. It takes a considerable amount of time and effort to improve the speed and accuracy of these skills. In terms of environmental factors, the new device is much quieter than the old system, which produced a noise level that disturbed and annoyed other workers in the area. Finally, because it is more versatile and controllable in its results, the new system will have benefits for future research endeavors in the area of tactile graphic displays.

Specifications for Plate Embossing Apparatus

for Raised Lines (PEARL)

The following are the specifications that were used in the design and development of the new embossing system:

I. Point symbols

    A. Should be capable of producing, at a minimum, the 1971 Nolan and Morris set of discriminable paper point symbols.

    B. Symbol elevation in paper should equal or exceed .025 inch for any given point symbol.

II. Linear symbols

    A. Should be capable of producing both continuous and interrupted lines.

        1. Should be capable of producing several dotted lines, each differing in the magnitude of its interdot interval.

        2. The spacing of dots within any given interrupted line should be constant.

    B. Symbol elevation in paper should be approximately .020" for any given linear symbol.

    C. Should be capable of producing curved lines (continuous and interrupted).

III. Areal symbols

    A. Should be capable of producing several discriminable areal patterns, both raised and incised.

B. Symbol elevation in paper should be approximately .010" - .015" for any given areal pattern (this includes background grids composed of either solid or dotted lines).

IV. Equipment design

A. Embossing mechanism

 1. Insertion and release of interchangeable heads (dies and stakes) should be simple and fast.

 2. Heads should be arranged and labeled in an organized fashion in an area easily accessible to operator.

 3. The plate transport mechanism should move the plate reliably and be easily and quickly adjustable (for different plate movement distances).

 4. Base of embossing stake ( ) should be flush with work surface.

B. Work surface

 1. Major part of surface area should be continuous (no breaks) to prevent plate hangups.

 2. Surface should be smooth and composed of a hard metal to prevent plate hangups and to permit erasure of mistakes (with hammer impacts).

 3. Surface should have a low reflectance to reduce glare.

 4. Surface should be well lighted, especially at the immediate work area (embossing head).

 5. Work surface must have enough clearance to allow 360° rotation of atlas plates (22" x 16").

V. Miscellaneous

   A. Foot controls for raising the foot of the plate transport
       mechanism and for operating the embossing mechanism must be
       provided to free the hands for plate manipulations.

   B. Operating noise should be considerably reduced from previous
       levels (93 dB$_A$ at ears of operator, 83 dB$_A$ at 12', 81 dB$_A$ at
       19').

In actuality, two machines were designed to carry out all of the
functions needed by the embossing system. A primary embossing machine
produces the linear symbols and most of the areal patterns (see Figure
1). A companion machine produces all of the point symbols and one of
the areal patterns. This latter machine contains a bank of 20 easily
selectable punch and die sets (see Figure 2).

Symbols Legibility

The primary objective of this study was to identify legible sets of point, linear, and areal symbols from a pool of prototype symbols that were designed for use with PEARL. This pool consisted of 19 point symbols, 16 linear symbols, and 14 areal symbols. Their structural characteristics were based on information from previous studies of tactile symbology and critical parameters of legibility, and on the capabilities and limitations of the new plate embossing system. The greatest differences between these new sets of symbols and previous ones are their generally higher level of relief (especially for the linear symbols), a greater variety of symbol types, and a significant improvement in their sharpness or clarity.

In contrast to previous studies, this one incorporated an incised parameter in symbol design. An incised linear symbol was included in the test set of lines, since Barth (1984) found it had a facilitative effort on graph-reading performance when used for the background grid. In addition, several areal patterns were tested in an incised form. In comparing raised with incised areal patterns, Barth (1983) found that raised patterns increased line-tracking time by 44%, line departure errors by 158%, point location time by 34%, and point location errors by 160%. Their addition to the test pool increased the size of the resulting set of legible areal patterns.

The legibility of the symbol sets was evaluated by the matching procedure used in the Tactile Graphics Kit study. Because of the rather large pool of symbols, it was not practically feasible to use

a pair comparison technique. The number of trials needed would have been prohibitive. A matching technique (examine a symbol and find it among the entire set) requires a minimum number of trials and, furthermore, is similar to the task actually performed when using a key in a tactile display. The one shortcoming of this method is that a rather large number of symbols must be sifted through on each trial (in the case of point symbols: 19). For younger students, attention span could be a problem here. Consequently, only older students (minimum grade level: 7) were used in this study. This is not expected to reduce the generalizability of the results, since previous studies on symbol discriminability (Nolan & Morris, 1971; Barth 1982) have found no effects attributable to grade level.

Contained within the symbol sets were several symbols which have the capability of conveying spatial direction. In the point symbol set, there was a staircase and an arrowhead. In the linear symbol set, there was a directional line composed of a string of arrowheads and composed of a string of V's. All of these symbols were tested in various orientations to determine the usefulness of their directional characteristics.

Finally, a preliminary evaluation was made of the interference of areal patterns on line perceptibility. Of necessity, some of the structural characteristics of lines and areal patterns are similar (for example, the use of solid and dotted lines in both). This may cause interference between particular lines and areal patterns,

although, even in the worst cases, the 2 to 1 elevation difference
might be expected to overcome this problem. The best way to examine
it would be to test each type of line combined with each type of areal
pattern. Once again, the number of displays and trials needed to
accomplish this would have been prohibitive for this study. Instead,
the two most frequently used lines (thin dotted, thin solid) were
tested in combination with the 10 raised areal patterns. This gave
some idea of what interference could be expected from particular areal
patterns for one of the most important line parameters: continuous--
interrupted. The information obtained may even be generalizable
(albeit tentatively) to other line types.

In order to evaluate the feasibility of this study (especially the
legibility matching tasks), five students in grades 7-12 from the
Kentucky School for the Blind served as pilot subjects. No problems
were encountered during pilot testing.

Method

Subjects

Forty-two students in grades 7-12 (grade placement or reading
level) participated in this study. All of these students used braille
as their primary mode of reading for a minimum of 3 years, were
enrolled in a regular academic program, and had no debilitating
physical handicaps other than impaired vision. Half were male; half
female. Mean grade level of the students was 9.7 (5D=1.7). Mean age
was 16.2 years (SD=2.1), with a range from 13 to 20 years.

Stimuli

Symbol sets. Three sets of symbols, consisting of 14 areal patterns,
16 lines, and 19 points comprised the test stimuli (In actuality, the
point symbol set consisted of 21 stimuli, since two additional
orientations of the arrow symbol were also included). All stimuli
embossed in zinc plates using PEARL and subsequently reproduced in a
paper medium (.006 inch in thickness). Each set of symbols was
arranged on a separate display, 11 inch wide by 11 1/2 inch high.

The 14 areal patterns (4 of which were incised) were reproduced
as 1 1/2 inch square patches, arranged in a format of 4 rows and 4
columns. Vertical and horizontal spacing between patterns was 3/4
inch. In order to control for position effects, 14 random arrangements
of the areal symbols were generated, resulting in the construction of
14 test displays.

The 16 linear symbols were reproduced in lengths of 2 inch,
arranged in a format of 8 rows and 2 columns. Vertical spacing
between lines was 1 inch; horizontal spacing was 3 inch. Sixteen
test displays were constructed, each containing a unique random
arrangement of the 16 lines.

The 21 point symbols were arranged in a format of 3 rows and 7
columns, with a horizontal spacing of 1 inch between symbols and a
vertical spacing of 1 1/4 inch. Twenty-one test displays, each with
a different (and random) arrangement of symbols, were constructed.

In addition to these displays, which contained an entire symbol
set, a single-symbol display was constructed for each of the point,

linear, and areal symbols. Each of these displays was approximately 4 1/2 inch wide and 2 1/2 inch high, with the symbol centered within it. See Tables 1-3 and Figures 3-5 for the specifications of the symbols evaluated in the legibility study.

Directional lines. Displays were constructed for testing the perceptibility of these lines' directionality. The lines used were (1) composed of a string of v's and (2) composed of a string of the arrow point symbol. Six spatial orientations of the directional lines were represented on the display: vertical--up; vertical--down; horizontal--right; horizontal--left; circular--clockwise; circular--counterclockwise. All line segments were 2 inch in length; all circles were 2 inch in diameter.

Staircase symbol. A special point symbol was designed to represent a staircase. It consisted of two parallel, dash-like solid lines, one of which is thinner and lower in elevation than the other. In order to test the perceptibility of this symbol's orientation, a display was constructed which contained four different orientations of the staircase symbol: left, right, up, down.

Arrow-symbol. In order to test the perceptibility of this symbol's orientation, a display was constructed which contained four different orientations of the arrow: left, right, up, down.

Raised-Areal-embedded lines. Two groupings of 6 displays (11 X 11 1/2 inch) were constructed, each display containing 5 areal patterns (3 sets of the 10 raised areal symbols) were 2 1/2 inch square. There was no spacing between the patterns. The 10 patterns

of one set had a one inch vertical line embedded in their centers.
The 10 patterns of a second set had a one inch horizontal line embedded
in their centers. The remaining set contained no embedded lines. In
one of the display groupings, the embedded line was a thin dotted line
(.024 inch in elevation). In the other, it was a thin solid line
(.020 inch in elevation). The positions of the 30 patches in the
displays of both groupings were randomly determined.

Incised-areal-embedded lines. Two additional groupings of 6
displays were constructed. These displays exhibited the same
characteristics as those described above, with the exception that
incised areal patterns were used.

See Figure 6 for an example of this type of display.

Procedure

Symbol sets. Each subject was tested individually. Basically
the subject's tasks were to examine a particular symbol (located in
the center of the 4 1/2 X 2 1/2 inch display) and then to identify
that symbol among the entire set of symbols in that class (point,
linear, or areal) on the 11 X 11 1/2 inch display (hereafter called
the comparison display). This matching task is similar to that which
is typically performed when a key is used in conjunction with a
tactile graphic. In all, each subject performed 51 discrimination
trials: 16 involving linear symbols, 14 involving areal patterns,
and 21 involving point symbols.

At the beginning of the session, each subject was instructed as
to the nature of the study and the tasks to be performed. The
single-symbol test display was always located to the subject's left,
the comparison display to the right. Both were placed on a clipboard
to prevent slippage during examination. The subject was instructed
to examine the test symbol on the left, then to examine each of the
comparison symbols on the display on the right, only then identifying
which one felt most like the test symbol. If an incorrect response
was given, that response was recorded, and the subject was told to
continue the search as above. No time limit was imposed and knowledge
of results was not provided.

Testing of one set of symbols (point, linear, or areal) was
completed before presentation of the next set. Each set was preceded
by two familiarization trials involving symbols not included in that
test set. The order of presentation of the point, linear, and areal
symbol sets was completely counterbalanced across subjects. The
order of presentation of individual and comparison displays within a
particular set were randomly determined for each subject. All random
orderings of stimuli were generated by the "Randomize" program
written for the Apple IIe.

Directional lines. Further testing of the directional lines
immediately followed the testing of symbol legibility. To assure the
directional quality of PEARL's version of the symbols, each subject
performed several tasks involving the identification of line direction.

A sample line was first presented for inspection, accompanied by brief instructions on its directional characteristics (Schiff found that some instruction on the use of this type of symbol was necessary). A second sample line was then presented and the subject was asked to move his/her finger in the direction indicated by the line. Twelve test trials (6 for each directional line) immediately followed the familiarization tasks. These trials consisted of 6 different spatial orientations of the directional lines: vertical--up; vertical--down; horizontal--right; horizontal--left; circular--clockwise; circular--countercloskwise. The order of presentation of the 2 test sets and the 6 displays within each set were randomly determined for each subject. Knowledge of results was not provided.

Staircase and arrow symbols. The purpose of this task was to ascertain whether or not the subjects could correctly identify the orientation of the staircase symbol and the arrow symbol. Testing of each symbol was done as follows: After an explanation of what the symbol represented two familiarization trials were given. The subject was asked: "If you walked up this stairway (followed this arrow) would you be going to the right, to the left, away from your body, or towards your body?" Four test trials then ensued. These trials consisted of four different symbol orientations: vertical--up; vertical--down; horizontal--right; horizontal--left. Order of display presentation was randomly determined. Knowledge of results was not provided.

Areal-embedded lines. This task involved the location of line segments embedded in areal patterns. A line segment different from those involved in testing was employed for purposes of familiarization. The subject then attempted to locate the embedded line segments on the training display. A second practice trial then followed, using the training display rotated 180°.

Two groupings of 12 test trials were then given. The order of presentation of the two test sets within each grouping (solid line segment, dotted line segment) as well as the order of the two groupings themselves (incised areal patterns, raised areal patterns) were completely counterbalanced between subjects. Subjects indicated the location of a line segment by tapping it with a finger and saying "here." No time limits were imposed and knowledge of results were not given.

For all of the experimental tasks discussed above, a fresh set of paper displays were used by each subject.

TABLE 1

Point Symbols Used in Legibility Study

	Symbol Elevation
□	.025"
◇	.026
▽	.026
○	.027
○	.028
●	.033
●	.027
∴	.028
⊙	.025
I	.025
∪	.027
I■	.018-.030
X	.030
∧	.027
T	.029
U	.027
S	.027
Z	.027
↑	.028
↓	.028
←	.028

TABLE 2

Linear Symbols Used in Legibility Study

	Symbol Elevation	Punch & Die Number	Plate Transport Setting
●●●●	.023	16	22
● ● ●	.023	16	35
●●●●●	.018	18	20
··········	.010	16^2	20
●●●●	.022	14^3	29
● ● ●	.022	14^3	39
:::::::	.021	17	24
——	.019	11	8
≡	.017	19	8
▬	.019	13^4	8
– – –	.021	11	8 (1/4" dash, 1/8" space)
‖‖‖‖	.020	20	20
‖‖‖	.020	20	35
➤➤➤	.028	point	--
>>>>	.027	point	--
i —	.012	11^2	8 (incised)

TABLE 3

Areal Symbols Used in Legibility Study

	Symbol Elevation	Punch & Die Number	Plate Transport Setting	Other
	.007	16^2	18	lines close as possible
	.007	16^2	28	line spacing also at 28
	.008	14	28	lines close as possible
	.009	14	38	line spacing also at 38
	.007	point	--	lines close as possible
	.012	12^2	8	lines close as possible
	.012	12^2	8	1/4" spacing betw/ lines
	.010	13	8	lines close as possible
	.008	13	8	5/16" spacing betw/ lines
	.012	12^2	8	1/4" grid
	.007	16^2	18	lines close as possible
	.008	14	28	lines close as possible
	.012	11^2	8	lines close as possible
	.012	11^2	8	1/4" grid

FIGURE 1. PEARL - Primary embossing machine.
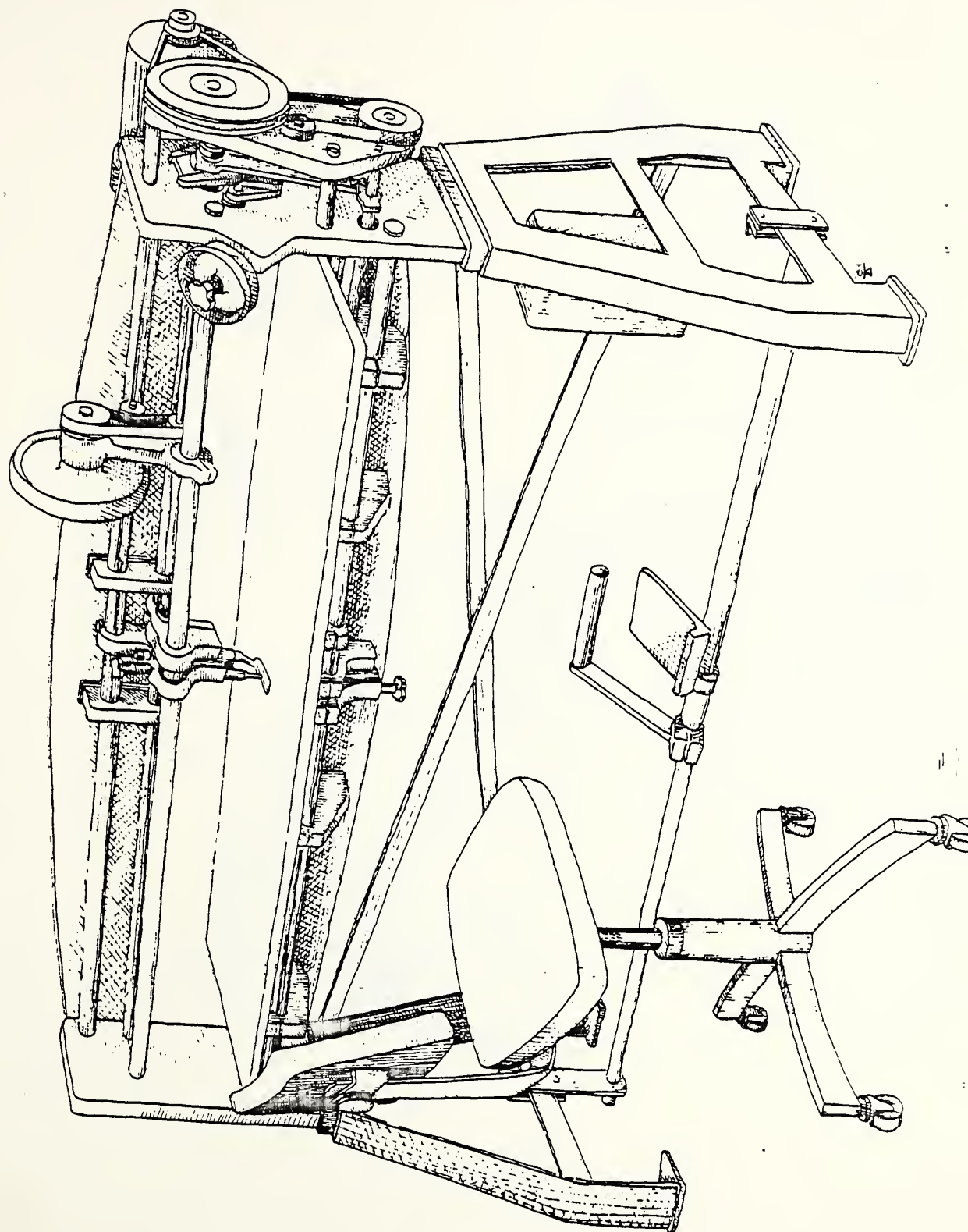
FIGURE 2. PEARL - companion embossing machine.
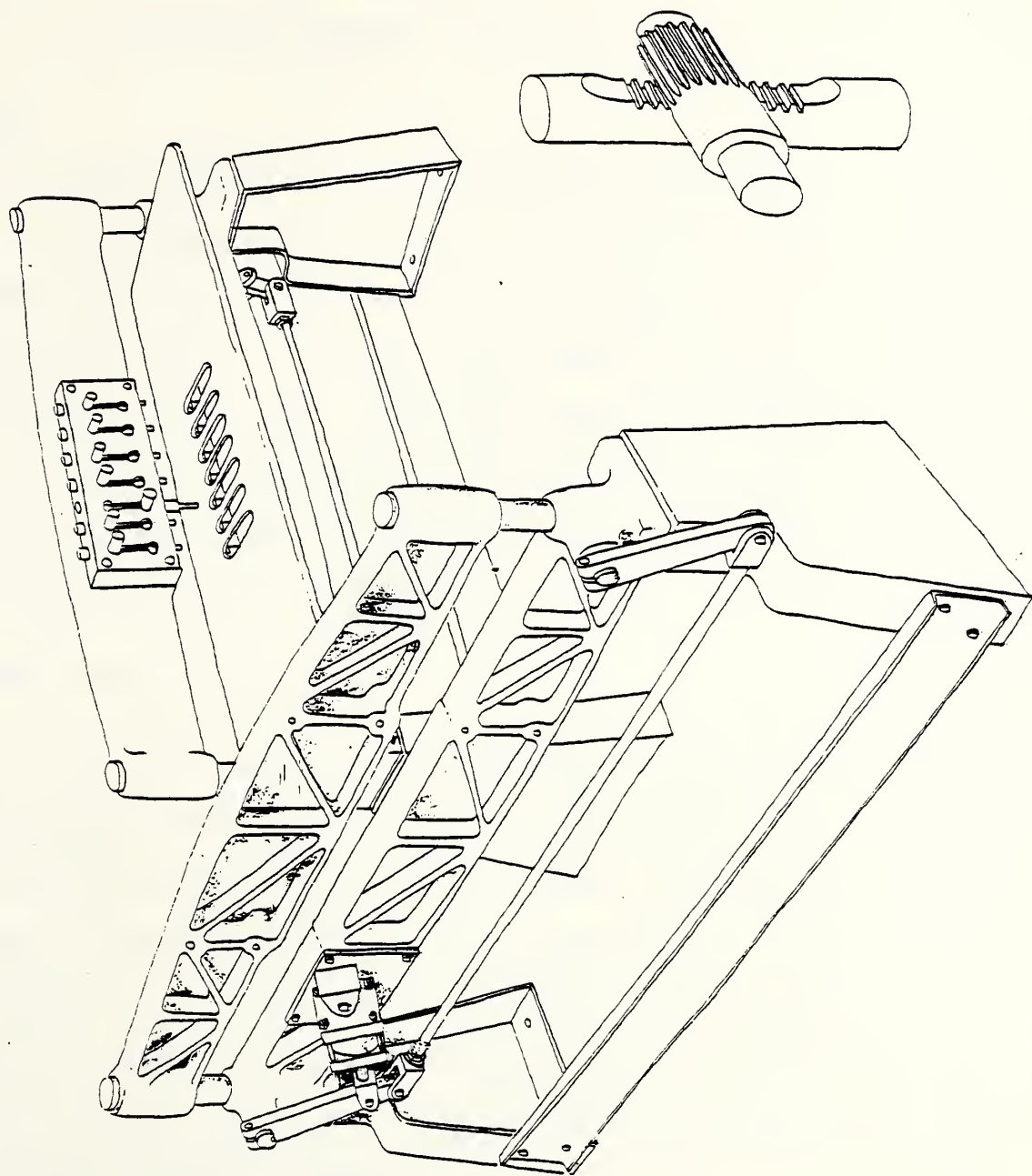
Appendix A

Instructions

(Legibility Testing - P E A R L)

Symbol Sets

"I'm from the American Printing House for the Blind in Louisville, Kentucky. As you probably know, we make most of your braille books. I have come to your school to ask some of you who read braille to help me with an experiment. I have with me a number of different patterns that will soon be used to make maps, graphs, and drawings, which you can feel with your fingertips. But, before they can be used, we have to know whether you can tell them apart. That is why I am here. Would you like to participate?"

Record name, grade level, age, and sex.

"(Name), I want you to help me with this experiment. On your left I have a line (shape, pattern) that I want you to feel. Examine it closely so that you know exactly what it feels like. Then examine each of the lines (shapes, patterns) on your right and then find the one or ones that feel just like the one on the left. When you think you have found a match, examine the one on the left again to make sure you have made the right choice. Then go on and see if there are any other matches. Here is a sample."

Present Sample A. Guide the subject's hand to the display on the left and then to the display on the right. Guide his/her fingertips over each of the 16, 14, 21 symbols, pointing out the number and display positions of the symbols contained in that set. Reiterate the experimental procedure: (1) Examine symbol on left, (2) Examine each symbol on the right, (3) Go back and find a correct match, making one last confirming check with the symbol on the left. Be sure the subject effectively examines the symbols on both displays and gets himself oriented to the task. Present Sample B. Alternate Samples A and B until both have been correctly executed. If the subject cannot comprehend the task (give a correct response for both Sample A and Sample B after 4 tries), discontinue and discretely excuse the subject. When both samples have been correctly identified, ask "Do you have any questions?"

"All right, if you have no other questions, we'll start: There are 16, 14, 21 of these altogether. After each one we'll go right on to the next one."

After completion of a given set of symbols, proceed with the next set by presenting the appropriate sample displays for that set in a fashion similar to that described above. Then proceed with the test trials for that set. Do not give knowledge of results for any set of test trials. When the tasks associated with the three sets of tactile symbols have been completed, say to the student:

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Directional Lines

"Now I want you to do something a little different. Place your finger on this line (direct finger placement) and examine it in both directions. When you move your finger in one direction, does if feel different than when you move your finger in the other direction? Can you tell which way the line is pointing?"

If incorrect, have student re-examine the line and give feedback as to the correct response. Then have the student examine the next sample line, again giving feedback. Proceed with the 12 trial runs, omitting knowledge of results. Then say:

Staircase and Arrow Symbols

"Here is another task I want you to perform. Feel the shape I'm placing your finger on. You have felt this shape several times today. This time, try to think of it as a stairway made up of two steps, one higher than the other. Can you feel the two steps? (If necessary, give instruction). If you walked up this stairway, would you be going to the right, to the left, away from your body, or towards your body? (If necessary, give additional instruction). Now examine this second sample. Which way do the stairs go?" (Give feedback).

Proceed with the four test trials, omitting knowledge of results.

"Now feel this shape. It is an arrow. Which way is it pointing? (If necessary, give instruction). Here is another arrow. Which way is it pointing?" (Give feedback).

Areal-embedded Lines

Place training displays in the front of student.

"Feel the line that is in front of you. (Have student examine it
vertically and horizontally). You are going to search a drawing and
find as many of these lines as you can. Here is the drawing. (Have
student briefly scan it for overall size and pattern placement).
When you locate a line, tap one of your fingers on it and say 'Here.'
Go as quickly as you can without missing any of the lines." (Rotate
display 180° and have student scan again; give feedback).

Place first test display in front of student. Have him examine the
line that is to be located (either dotted or solid).

"Here is another drawing. (Have student briefly scan it). I want
you to find as many lines as you can. Go as quickly as you can
without missing any of the lines." (Proceed with remaining test
displays of that set and then go on to the displays in the second
set, repeating the above procedure).

Repeat above procedure for second grouping of displays (either incised
or raised areal patterns).

NATIONAL 35-116 Made in U.S.A.
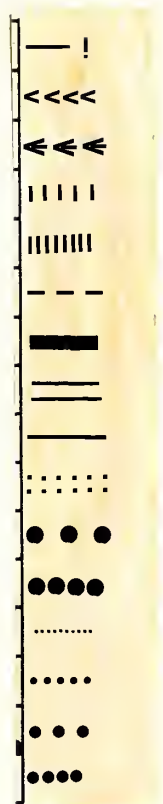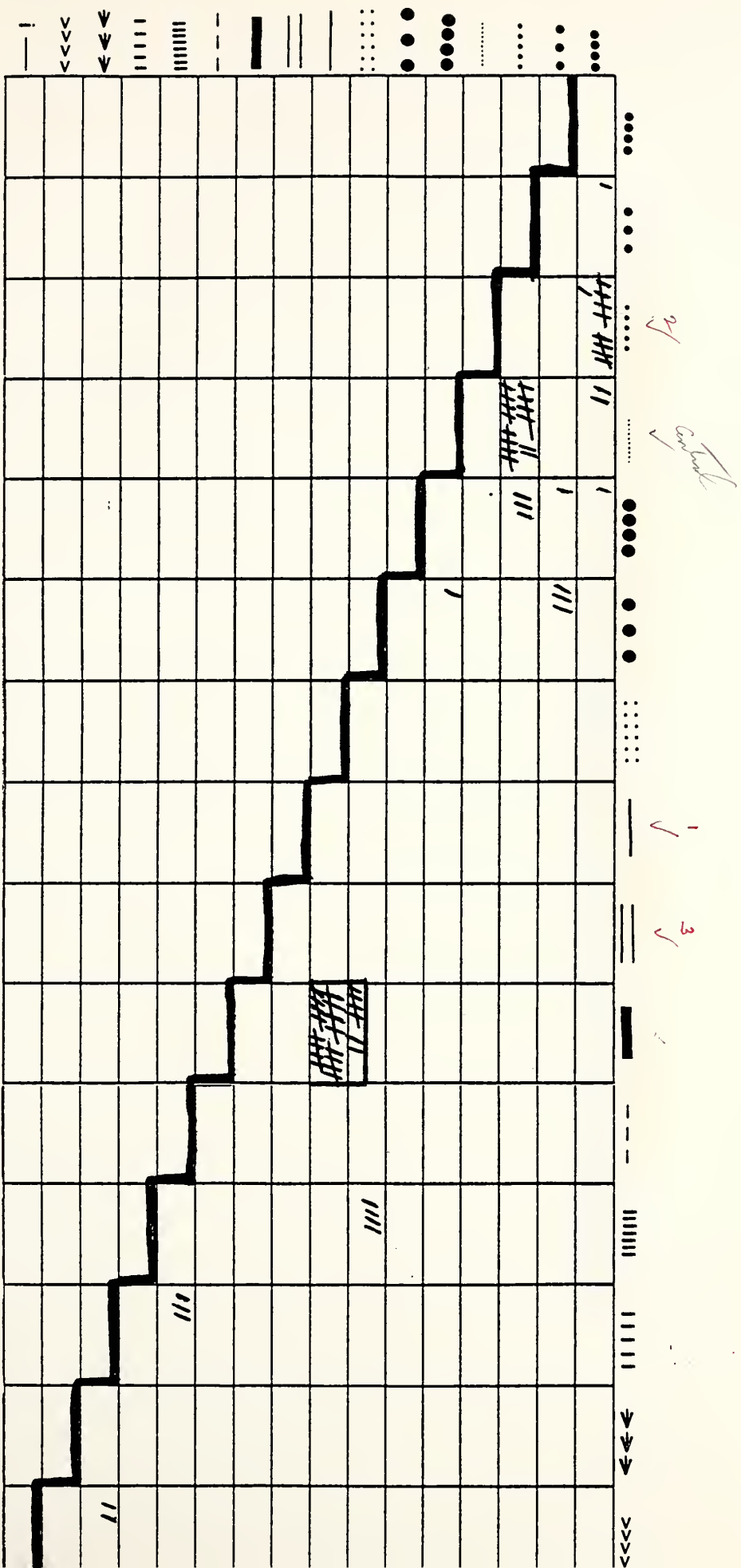
NAME	DIR. LINE PREFERENCE	TOTAL TIME			
		RAISED AREAL DOTTED LINE (14)	RAISED AREAL SOLID LINE (15)	INCISED AREAL DOTTED LINE (16)	INCISED AREAL SOLID LINE
Mike I	A	71	77	43	44
Mike L	V	45	57	22	32
Carol Lo	N	41	47	35	34
Lorrie	N	57	62	28	30
Mike	V	36	45	20	34
Donaita	V	58	89	19	38
Denny	N	39	50	26	32
Theresa	A	33	34	18	19
Monty S	N	34	56	17	16
Tona S	N	30	69	22	24
Michelle	N	27	47	19	21
Stacy	V	39	121	24	23
Michele	N	47	47	45	28
Jeff	V	37	53	32	48
Sarah	N	41	59	33	28
Jan Rok	N	49	59	40	52
Lilian	N	39	40	33	43
Kevin S	N	68	86	26	31
Brad M	N	33	47	21	29
Tony N	N	50	93	44	58
David S	V	40	60	25	34
Tim Eg	N	53	71	29	40
Andrew	A	54	66	41	58
Jerry K	N	49	88	34	47
Rose S	V	45	47	34	40
David R	V	45	80	43	39
Tony Sir	V	24	31	17	26

TOTAL TIME

Column groups — Errors: STAIRCASE SYMBOL (R, L, U, D) · ARROW SYMBOL (R, L, U, D) · DIRECTIONAL LINE: ARROW (L, R, U, D, C, CC) · DIRECTIONAL LINE: "V" (L, R, U, D, C, CC) · DIR. LINE PREFERENCE · Total Time (Raised Areal Dotted Line, Raised Areal Solid Line, Incised Areal Dotted Line, Incised Areal Solid Line)

NAME	GRADE	AGE	SEX	SC R	SC L	SC U	SC D	AR R	AR L	AR U	AR D	DA L	DA R	DA U	DA D	DA C	DA CC	DV L	DV R	DV U	DV D	DV C	DV CC	DIR LINE PREF	Raised Areal Dotted	Raised Areal Solid	Incised Areal Dotted	Incised Areal Solid
Mike Dixon	8	15	M																					A	71	17	43	44
Mike Lawler	8	13	M																					V	45	57	22	32
Carol Lockridge	10	17	F					✓	✓			✓	✓		✓			✓	✓			✓	✓	N	41	47	35	34
Lorrie Bennett	10	17	F																					N	57	62	28	30
Mike Riley	9	15	M																					V	36	45	20	34
Donaita McClendon	12	17	F			✓		✓						✓										V	58	89	19	38
Denny Bowers	8	14	M																					N	39	50	26	32
Theresa Fleenor	8	14	F																					A	33	34	18	19
Monty Seeberns	7	13	M																					N	34	56	17	16
Tona Snoeberger	8	14	F			✓		✓							✓			✓						N	30	69	22	24
Michelle Huff	7	14	F																					N	27	47	19	21
Stacy Todd	9	16	F																					V	39	121	24	23
Michele Barret	9	16	F																					N	47	47	45	28
Jeff Cope	9	17	M					✓		✓		✓						✓	✓					V	37	53	32	48
Sarah Huff	11	17	F																					N	41	59	33	28
Jan Roberts	8	14	F																					N	49	59	40	52
Lilian Roberts	12	19	F																					N	39	40	33	43
Kevin Sparks	12	19	M																					N	68	86	26	31
Brad Mundt	9	16	M																					N	33	47	21	29
Tony Nezol	7	14	M	✓	✓			✓						✓	✓	✓	✓	✓						N	50	93	44	58
David Sampson	8	13	M																					V	40	60	25	34
Tim Eggerling	12	19	M					✓																N	53	71	29	40
Andrew Stahmen	11	17	M																					A	54	66	41	58
Jerry Kuhlman	8	13	M																					N	49	88	34	47
Rose Savisky	8	14	F																					V	45	47	34	40
David Ray	12	18	M																					V	45	80	43	39
Tony Simmons	12	20	M																					V	24	31	17	26

NAME	GRADE	AGE	SEX	ERRORS STAIRCASE SYMBOL				ERRORS ARROW SYMBOL				ERRORS DIRECTIONAL LINE: ARROW						ERRORS DIRECTIONAL LINE: "V"						DIR. LINE PREFERENCE	TOTAL TIME RAISED AREAL DOTTED LINE	RAISED AREAL SOLID LINE	INCISED AREAL DOTTED LINE	INCISED AREAL SOLID LINE
				R	L	U	D	R	L	U	D	L	R	U	D	C	CC	L	R	U	D	C	CC					
Sandra Williams	11	17	F	✓	✓				✓																A	25	40	20	21
Brent Russert	14	19	M																						A	44	62	29	44
Steven Giggar	10	17	M																						N	33	46	19	24
Susie Bowers	12	20	F																						N	45	52	28	36
Richard Schubert	9	15	M																						A	46	51	48	47
Mike Hammond	9	15	M																						A	27	34	19	21
Sandra Love	11	17	F																						A	30	32	19	21
Joe Lanier	11	17	M																						N	13	23	12	13
Kathy Readus	12	17	F																						V	27	42	24	25
Chris Bonebreke	12	19	F																						N	31	42	23	27
Kim Phipps	7	13	F																						N	26	45	17	24
Dawn Petty	11	16	F	✓		✓		✓		✓		✓	✓	✓		✓	✓	✓		✓	✓	✓				V	44	64	20	30
Melody Osbourne	10	17	F																			✓				V	36	64	36	29
Regina Smith	9	17	F						✓																	N	34	40	20	23
Robert Bernier	10	19	M																						N	59	106	22	37

21 M
21 F

$\bar{X} = 9.7$ $\bar{X} = 16.2$

$SD = 1.7$ $SD = 2.1$

PEARL LEGIBILITY STUDY
(Data Sheets)

NAME:_____   GRADE LEVEL:_____

SCHOOL:_____   AGE:_____

                                      SEX:_____

CONSENT:_____Yes _____No
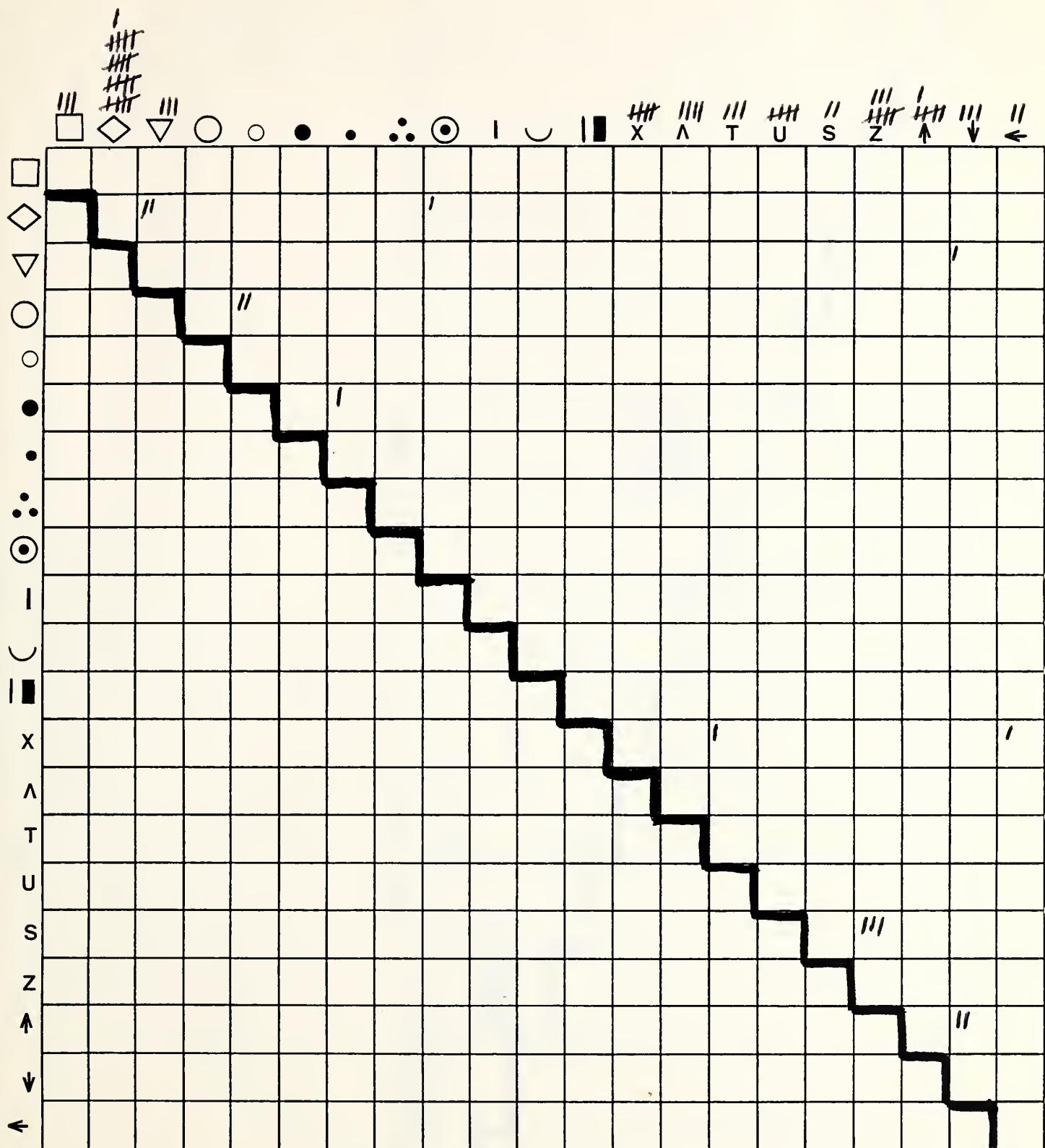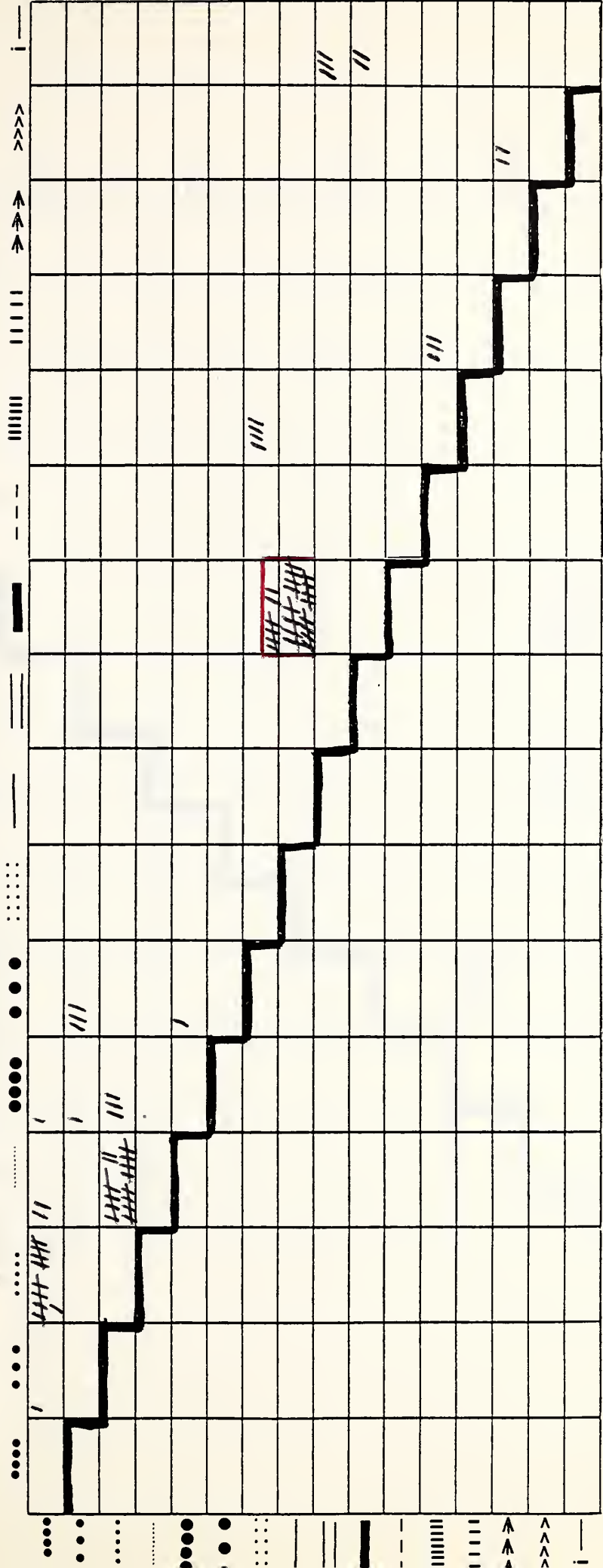
	::::	:::	•••	••	88	‖‖‖	‖‖	▌▌▌▌	▌▌	#	i:::	i•••	i‖‖	i#
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88														
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i#														
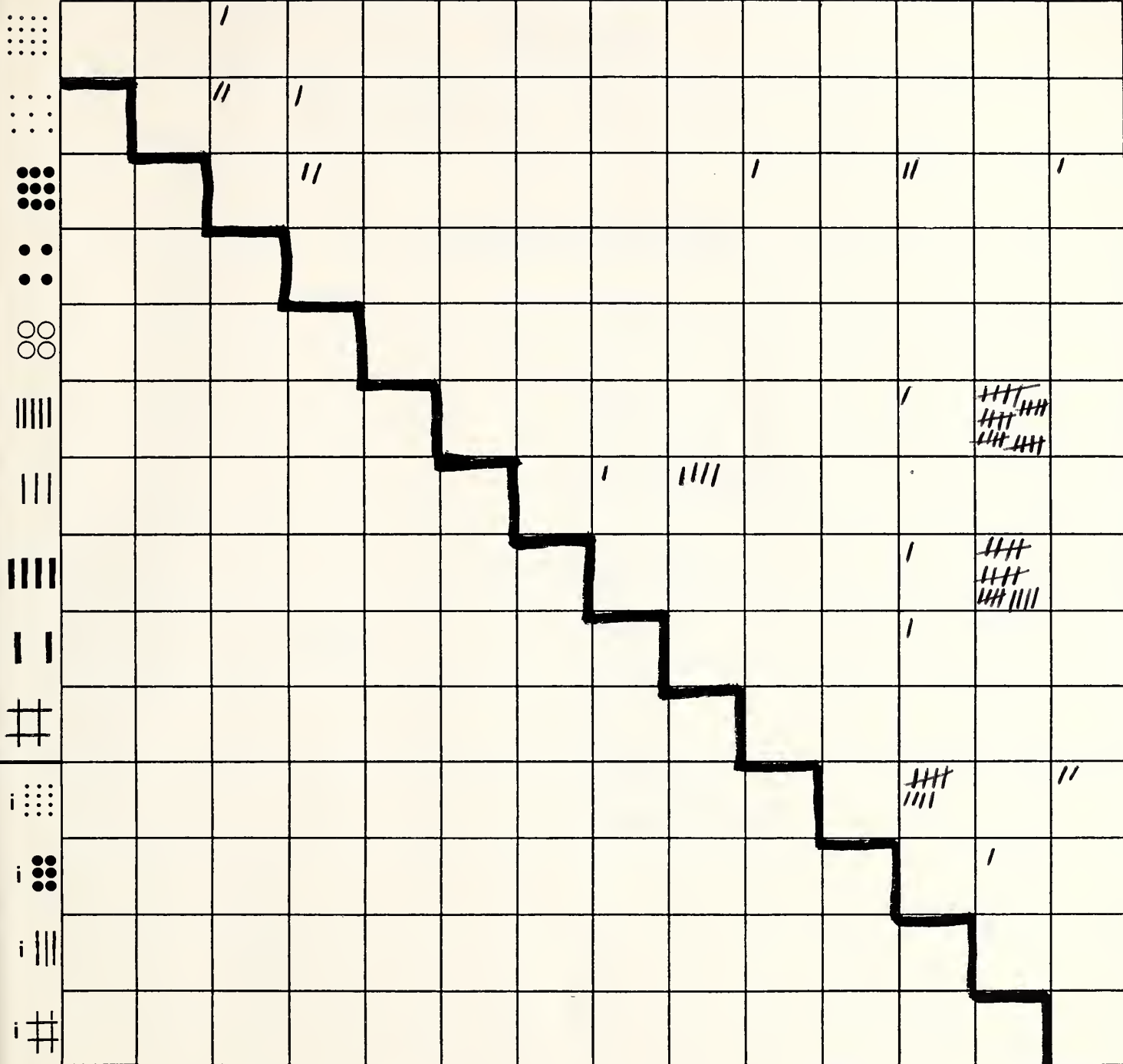
Staircase Symbol

Errors: right_____   left_____   up_____   down_____

Arrow Symbol

Errors: right_____   left_____   up_____   down_____
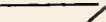
Directional Line: Arrow

Errors: _____ left
                     _____ right
                     _____ up
                     _____ down
                     _____ clockwise
                     _____ counterclockwise

Directional Line: V

Errors: _____ left
                     _____ right
                     _____ up
                     _____ down
                     _____ clockwise
                     _____ counterclockwise

AREAL-EMBEDDED LINES

Dotted: _____╱

 Solid: _____╱

ERRORS

	::::	:::	●●●	●●	88	‖‖‖	‖‖	‖‖‖	‖ ‖	#
V		卌	卌 / 卌 / 卌 ‖	卌 /	卌 / 卌	‖	卌 / ‖		/	卌 / 卌 / ‖
H	/	‖					‖			‖‖‖
B					/		‖‖‖	‖	卌	卌 / ‖‖‖

SPEED

Plate	Time(sec.)
1	
2	
3	
4	
5	
6	
T	

AREAL-EMBEDDED LINES

Dotted: ✓

Solid: _____

ERRORS

V ///	////	///	////		/		/		////
H	卌 //								
B									/

SPEED

Plate	Time(sec.)
1	
2	
3	
4	
5	
6	
T	

AREAL-EMBEDDED LINES
(Incised)

Dotted:_____✓_____

Solid:_____

ERRORS

	i ⠿	i ⣿	i ╫	i ╫
V				//
H				
B				

SPEED

Plate	Time(sec.)
1	
2	
3	
4	
5	
6	
T	

AREAL-EMBEDDED LINES
(Incised)

Dotted:_____

Solid:___✓____

ERRORS

	i ⋮⋮⋮	i ⦂⦂	i |||	i #
V	/	/	//	⫽⫽⫽⫽ /
H				
B				

SPEED

Plate	Time(sec.)
1	
2	
3	
4	
5	
6	
T	